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PROCEEDINGS

OF THE

THIRD ANNUAL TECHNICAL SEMINAR

EXCESS NUTRIENTS IN RECEIVING STREAMS

JUNE 9, 1966

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Proceedings of the Third Annual Technical Seminar of the
OWRC Professional Engineers Group, held on June 9, 1966 in the
Auditorium of the OWRC Laboratory.

The general topic was: "Excess Nutrients in Receiving
Streams."

Dr. H. B. N. Hynes, Chairman of the Biology Department,
University of Waterloo, presented: "Excess Nutrients as a Pollution
Problem in Streams."

Mr. M. Johnson, Biologist with the Biology Branch of the
OWRC Division of Laboratories at the time of the Seminar, discussed
"Commission Programs in Relation to the Nutrient Problem."

The proceedings include both papers as well as a summary
of the discussion.




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EXCESS NUTRIENTS AS A POLLUTION PROBLEM IN STREAMS

by H.B.N. Hynes
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In truth very little is really known about the influence of excess nutrients on streams. We know a fair amount about the effects of pollution, but most of our knowledge is based on field studies and toxicity tests. When we talk about the effects of nutrients, by which in this context we mean plant nutrients, we are basing our assumptions primarily on inference and very little on hard facts. Quite possibly some of the effects we attribute to nutrients, and while doing so we are thinking of the "NPK" of agriculture, may be caused by other, more subtle, parameters of pollution. For instance, it is well known to phycologists that many algae will not grow in culture media without the addition of such things as soil-extract; so it is undoubted that they need substances, possibly quite elaborate ones, which are not available in simple salt solutions. We also know that, like higher plants, many algae require minute amounts of micro-nutrients (Eyster 1964). Whether or not any such substances are needed in especially large amounts by the plants which burgeon in polluted water, and whether these rather than large amounts of the "conventional" nutrients are what cause their unwanted growth remain to be discovered.

On the other hand the effects of nutrients on lakes have been well studied and are fairly well understood. It will perhaps therefore pay us to study these briefly and then to see how much of this knowledge can be applied to running water.



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It was long ago shown that lakes in different geological areas differ in the amounts of phytoplankton they develop. Lakes on soft soluble rocks tend to have more plankton, and their waters to contain more phosphorus (P) and saline nitrogen (N), than those on hard rocks. Deevey (1940), after a careful analysis of data from nearly 50 lakes in Connecticut and New York, concluded that P was of first importance in controlling phytoplankton growth and N of second significance. It has since been shown by many investigators that increases in these two elements in lake water, caused primarily by pollution, lead to algal blooms. For example Oscillatoria rubescens, a notorious alga of "enriched" lakes, first appeared in Lake Washington in 1955 when the P content of the hypolimnion reached high levels (it rose from 0.023 mg/l in 1950 to 0.083 mg/l in 1957 (Anderson 1961)). Similarly the numbers of troublesome blooms in the Wisconsin lakes showed very definite correlation with the amounts of N and P being added to them (Lackey and Sawyer 1945). As ordinary domestic sewage contains 15 - 24 mg/l of N and 2 - 4 mg/l of P (Sawyer 1952) it is not surprising that it soon steps up the amounts of these materials available in polluted lakes.

In most studies the indications are that P is the limiting factor, increase of which leads to plankton blooms, but on occasion N has been shown to be in short supply. For instance Gerloff and Skoog (1957) showed that shortage of N more often limited growth of Microcystis aeruginosa in southern Wisconsin lakes than did P, and they pointed out that the required ratio for this species, of N:P is 60:1. They also showed that in some lakes iron was in short supply. In other places silicon (Lund 1964) and even sulphate (Beauchamp 1953) have been shown to be limiting factors for phytoplankton.

We are here, however, considering blooms of planktonic algae, and these are only rarely of consequence in running water, and then only in large rivers. It is pertinent, therefore, to note that artificial fertilization of lakes can also lead to excessive growth of filamentous algae. Ball (1950) reports that this occurred in the second year of fertilization, for fishery purposes, of two lakes in Michigan; and some very nice work by OWRC has shown that P enrichment causes outbreaks of Cladophora on the shores of Lake Huron. We can conclude therefore that sessile algae are likely to be affected in the same way as plankton.

The relative importance of N and P probably varies from lake to lake, and although much work stresses the greater importance, usually, of P this may be because some common plankton algae can fix atmospheric nitrogen. Dugdale (Dugdale and Dugdale 1962, 1965, Dugdale and Neess 1961) showed that *Anabaena* fixes large amounts of molecular N when saline N is in short supply, as long as there is sufficient P present. Thus while some other blue-green algae do not fix nitrogen, there is always the possibility of buildup of N in a lake. Perhaps this may occur also in streams, because both Nostoc, which is a genus of damp soil and Oscillatoria, many species of which occur in streams, are known to be nitrogen fixers (McKee 1962).

An important property of lakes is their ability to retain nutrients, particularly P. Early work by Mortimer (1941, 1942) showed that this is caused by the fact that ferric phosphate is insoluble and is precipitated to the lake floor, where the phosphate can again be released by reduction of the ferric iron to the ferrous form. In lakes in which the bottom water remains oxygenated most of the time, the phosphate tends to remain trapped and unavailable for plant growth

(Holden 1961), but when there is a long period of deoxygenation in the hypolimnion phosphate is released into the water. This seems, however, to be a fairly slow process because Tucker (1957) found that measurable amounts of P appeared at the bottom of Douglas Lake, Michigan, only after 8 weeks of deoxygenated conditions. It is this release of P from bottom deposits by low redox potentials which accounts for the fact that lakes, which over a period of years have been steadily enriched, often quite suddenly produce massive blooms. This occurs in the summer after they first completely deoxygenate their bottom water for sufficiently long to bring significant amounts of P into solution. This problem of phosphate enrichment of lakes has been discussed by several authors, e.g. Ohle (1955) Hasler (1947) Hynes (1960) and does not really concern us here except in so far as it may effect lake outflows. Clearly, an unproductive lake on the course of a stream will tend to reduce nutrients in the outflow. Lake Tahoe retains 89% of the N and 93% of the P that it receives (Ludwig et al 1964), although these are particularly high values associated with an exceptionally oligotrophic lake. On the other hand it is possible that a lake which has reached the blooming phase of enrichment may actually enrich the river below it. As far as I know this has not been studied.

One thing that is certain is that, even though an enriched lake may lose a lot of nutrients in the form of flying insects or of fish caught by man, these represent only a small fraction of the amounts being added (Vallentyne 1952, Curl 1959).

The actual chemistry of the various nutrients varies in complexity. Potassium (K) is a common constituent of many rocks and goes

into simple ionic solution; it seems rarely, if ever, to be in short supply. Nitrogen may be present as ammonium or nitrate ions (more rarely as nitrite), and is available in both common forms for algal growth, although more readily as nitrate (Chu 1942, 1943). Phosphate, on the other hand, is usually sparingly present as simple inorganic orthophosphate. In lake waters much of it is present in organic form or as particles. It is released from these by bacterial action and then becomes available for plants, but one interesting feature about P metabolism is that ionic phosphate is taken up very fast. Thus, even during periods of bloom, little free phosphate is to be found in the water, and the turnover time, the uptake and release of P, can be very short and measurable in minutes (Rigler 1964). Only a very few percent, sometimes very little indeed, of the total P is therefore available in the water at any one time. Moreover, at least some algae, possibly most, can absorb phosphate greatly in excess of their immediate needs and go on dividing and reproducing in the absence of any further supply (Mackereth 1953).

These phenomena have, of course, some bearing on the availability of P and concentrations which can curtail growth. However, it is possible to say that, in culture, many algae require 0.3 - 1.3 mg/l of N and 0.09 - 1.8 mg/l P for optimum growth, and that below 0.1 mg N and 0.009 mg P per litre growth is limited (Chu 1942, 1943). These figures, particularly for P, correspond fairly well with field data (Mackenthun et al. 1964).

One last point about nutrients in lakes which may be relevant to stream conditions is the suggestion that hot weather may, by greatly lowering redox potentials in littoral deposits, release phosphate

into surface waters at times of particular need (Hutchinson 1957). This would be difficult to detect because of its immediate uptake, but it may be of considerable biological significance.

Now how can we apply this information to the running water habitat? Presumably there is no buildup of fertility as in lakes, because of the steady passage of the water. Even if ferric phosphate is formed, it will not normally be reduced to the ferrous state and release ionic phosphate, because of the ready availability of oxygen. On the other hand it is just possible that long periods of low flow in hot weather could release phosphate in stagnant areas or deep pools in the way that is suggested as occurring in the littoral zones of lakes.

Usually, however, running water is dependent for its nutrients on what flows into the stream. This can be quite a considerable amount. Cultivated land in Illinois has been shown to yield an average of 0.1 lb of phosphate per square mile per day (Engelbrecht and Morgan 1961), and in Wisconsin agricultural land contributes about 12 lb of N and 0.6 lb of P per square mile per day (Sawyer 1947). Urban land runoff contributes considerably more than this (Weibel et al. 1964), and this coupled with sewage and farmyard drainage, some of which reaches all streams in inhabited areas, means that most stream environments are well supplied with nutrients even before any formal pollutional load is applied to them. In this connection it should be recalled that raw sewage, which is the form in which small amounts of pollution reach streams in more remote areas, contains more P and N than the effluent from treatment plants (Rudolf's 1947). It should also be noted that the P content of sewage has been rising

steadily in recent years because of the advent of synthetic detergents, which are usually packed with phosphatic fillers. Indeed the P content of sewage is now three to four times its prewar value (Stumm and Morgan 1962), and in my experience most streams in inhabited areas, even well above regular sewage works, are nowadays a little more inclined to foam than they used to be. This probably implies that they contain rather more nutrients than they did, and that even "clean" streams are now to some extent enriched.

It was long ago suggested that flowing water is physiologically richer than still water containing the same amounts of dissolved substances. This is because the turbulent movement prevents the buildup of a depleted shell of water around actively metabolising organisms (Ruttner 1926). Whitford (1960a, 1960b, Whitford and Schumacher 1964) has since shown that this very definitely applies to plants in running water, and that they take up more nutrients and grow faster in currents. We can conclude therefore that the lower limits for algal growth which apply in still water may be a bit high when applied to running water, and that nutrient concentrations which seem rich in lakes are really very rich in streams. One must not, however, forget that planktonic algae do actually sink through, or, in the case of some blue-green algae, float up through, the water so even in still water this matter of the importance of depleted immediate surroundings may not apply in full measure to plankton.

As mentioned above, we do not know whether N-fixation occurs in running water. Quite probably it does not because, as we have seen, this phenomenon normally occurs only when N is in short supply and P is adequate. This is not likely to be a situation which would develop

in streams. Moreover, the N:P ratio in sessile stream algae is about 16:1 (Kevern and Ball 1965), which is much less than the ratio required by the particularly protein-aceous blue-green plankters mentioned earlier.

In fact stream algae have been shown to grow particularly well at N concentrations of 15 mg/l and to grow more rapidly, in the presence of adequate P, as the N content is raised above that level (Flaigg and Reid 1954). This is, as can be seen from figures given above, just about the range of nutrient content in domestic sewage. It is, therefore, perhaps not surprising that the most obvious effect of sewage enrichment of streams, as opposed to effects produced by deoxygenation and other parameters associated with organic matter, is massive growth of algae.

This effect has been documented by Hynes (1960), and has been observed to result from the diversion of sewage into a stream below the Madison lakes in Wisconsin (Mackenthun et al. 1960). Probably much of this effect is directly attributable to nutrients alone, as similar outbreaks of algae are observed in South African rivers where they cut through rocks which are especially rich in nitrates and phosphates (Oliff et al. 1965). We, however, do not know why certain genera tend to be encouraged and others apparently not. Well known algae of waters enriched by pollution are Stigeoclonium, Cladophora, Ulothrix, Rhizoclonium, Oscillatoria, Phormidium, Gomphonema, Nitzschia, Navicula and Surirella. Why do we get these and not others? Do they perhaps have a particular demand for some types of organic matter? Are they more encouraged by high nutrient contents than others and is what we observe merely the end product of competition?

These and many other questions can be answered only by experiments, preferably field experiments. And we should do them soon. Each year we use more phosphorus filled detergents, we increase in number and hence, in sewage output and we add more fertilizers to the land. Very soon, except in the remote north, we shall be hard put to it to find an unenriched stream on which to carry out the experiments.

We also do not know why, when certain algae are stimulated to excessive growth, there are always associated changes in the invertebrate fauna. Mayflies, stoneflies and caddisworms tend to disappear, and midge larvae, some crustaceans and some molluscs to increase. The reasons behind these changes are probably complex, but here again much could be found out by experimental enrichment of clean streams without the complications inherent in simple observation of the effects of purified sewage.

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COMMISSION PROGRAMS IN RELATION TO THE NUTRIENT PROBLEM

by Murray G. Johnson

Biology Branch

Ontario Water Resources Commission

INTRODUCTION

A general appreciation of the importance of excess nutrients in watercourses receiving wastes of many types has developed over the last couple decades. Fortunately many groups within the Commission have turned their attention in part towards the many problems concerned with the origin, effects and removal of nutrients. I propose to describe some of the projects undertaken by our biologists in this field. However, I shall take full responsibility for the interpretation and particularly the speculation, because I am sure that all I say will not go unchallenged. I would like to discuss the sources of nutrients, mainly on the basis of studies carried out by G. E. Owen and myself. I hope that our experience in the biological survey program will be of interest in relation to effects of domestic wastes due, in some cases, not directly to the usual loading of putrescible organics, but to nutrients. My thoughts on nutrient removal are speculations based on a minimum of original data, but I hope they may arouse some discussion tonight. If I seem to spend most of my time discussing phosphorus, I suppose I am as guilty as most in neglecting the many other essential elements.

THE SOURCES OF NUTRIENTS

The annual yield of phosphorus from six selected watersheds in the Toronto region was examined during 1964 and 1965 (West Humber River, German Mills Creek, Highland Creek, Little Rouge River and the Stouffville and Altona branches of Duffin Creek). A discharge-phosphorus rating curve was calculated and applied to the hydrograph of each watershed to develop these estimates.

The average yield of phosphorus from the three agricultural watersheds was $400 \text{ lb PO}_4/\text{mi}^2/\text{yr}$. This estimate is of the same order of magnitude as $700 \text{ lb PO}_4/\text{mi}^2/\text{yr}$ from agricultural drainage in the Madison Lakes area of Wisconsin (Sawyer, 1947) and $665 \text{ lb PO}_4/\text{mi}^2/\text{yr}$ attributed to land drainage on an Illinois watershed (Engelbrecht and Morgan, 1961). Although the yield of phosphorus from agricultural land drainage is doubtless a significant contribution, it would represent a very small proportion of the amount of fertilizer which is added to the land in contemporary agriculture, which is probably close to $10,000 \text{ lb PO}_4/\text{mi}^2/\text{yr}$ in our study area. Nonetheless, one could claim that most of the yield of phosphorus originated in commercial fertilizer. I find that one might just as easily assume that streambank erosion was a main source, and this can be shown rather convincingly.

The Metropolitan Toronto & Region Conservation Authority examined streambanks above the Ebenezer Reservoir site on the West Humber and found about $360,000 \text{ ft}^2$ of eroded bank. Soil samples from these banks contained about 0.2% total phosphorus. Some rough calculations showed that the loss of about 3 in. of soil each year

from these banks would account for the estimated total annual yield of phosphorus of about 18,000 lb from that watershed. I know of several banks which have retreated at a far greater rate. Agriculture sometimes has been accused of adding excess nutrients to our watercourses, but probably the means has been misjudged in view of the fact that the main cause of bank damage is streamside grazing by cattle and much of the phosphorus must be from eroding banks. No government agency to date has paid much attention to the streambank erosion problem.

The average yield of phosphorus from two urbanized watersheds was 22,000 lb $\text{PO}_4/\text{mi}^2/\text{yr}$ (24,000 and 20,000 lb from the Highland and German Mills watersheds) which was about 50 times greater than the yield from agricultural watersheds. Yields from the two plants were monitored and, of course, accounted for most of the total.

Highland Creek was of particular interest because the watershed is well serviced and sanitary wastes are delivered to the sewage treatment plant near Lake Ontario. We were able to measure the yield of phosphorus in surface runoff separate from the yield in sanitary sewage delivered to the plant. The estimated yield in runoff was 3,000 lb $\text{PO}_4/\text{mi}^2/\text{yr}$, about 7 times greater than the mean yield from the three agricultural watersheds. Approximately 29,000 lb $\text{PO}_4/\text{mi}^2/\text{yr}$ were contributed in sanitary wastes on the Highland Creek watershed, making the gross (sanitary wastes plus runoff) contribution equal to 32,000 lb $\text{PO}_4/\text{mi}^2/\text{yr}$. Thus about 90% of the gross contribution from this watershed passed through the sewage treatment plant. Removal of phosphorus by secondary treatment of municipal wastes resulted in a net yield about 25% less than the gross contribution.

Tertiary treatment to remove 90% of the phosphorus in sanitary wastes would effect about 80% reduction in the gross contribution. The point to be made here is that not all of the increased yield of nutrients due to urbanization will be directed to the sewage treatment plant for possible removal.

Yields of nitrogen from these watersheds were, of course, much greater than phosphorus yields but other differences were noted. Yields from agricultural watersheds averaged about 17,000 lb N/mi²/yr and from two urbanized watersheds about 60,000 lb N/mi²/yr, only three to four times the yield from agricultural watersheds. The ratio of phosphorus to nitrogen (P:N) in the yields from agricultural watersheds was 1:100 while the ratio was 1:10 in the case of urbanized watersheds. Superficially these data indicate that nitrogen should not be in limiting supply while phosphorus might be in the "agricultural" watercourse. However, phosphorus is very abundant in the "urbanized" stream, the ratio is much closer to the ratio of P:N found in plants, and perhaps nitrogen is sometimes in limiting supply in these very productive waters. It is evident at least that the P:N ratio seems to be nearer optimum when substantial amounts of treated sewage are added to a stream and both elements are in good supply at the same time.

EFFECTS OF EXCESS NUTRIENTS

Often we associate a decline in oxygen and perhaps absence of fish and other changes in the biota to excessive BOD levels and suspended solids concentrations. These are easily measured parameters and the Commission has objectives, for BOD at least, for watercourses.

In many cases the comparison is perfectly valid, but in other cases we find quite acceptable levels of BOD and solids yet extremely low concentrations of oxygen. The Upper Credit River is an example. Minimum concentrations of oxygen less than 1 ppm were observed at two stations below Orangeville in 1965 while the BOD was between 2.8 and 4.6 ppm and the level of suspended solids was quite low. The point at which the lowest minimum concentration of oxygen was found during a survey of the Stouffville branch of Duffin Creek was farther downstream than points where increased levels of BOD and solids were detected.

In these and similar cases we find excessive growths of aquatic plants, usually filamentous algae or sago pondweed and sometimes both. We conclude, therefore, that the respiratory demand of green plants during darkness is the main factor in depleting the oxygen supply, rather than the respiration of heterotrophs. The timing of the yield of nutrients from watersheds of various land use certainly must be of ecological significance. About 75% of the annual yield of phosphorus from our three agricultural watersheds was discharged during February, March and April at a time when excessive turbidity and low temperatures would be expected to limit productivity. Only 11% of the total yield occurred during the period, May to September. Yields of phosphorus from urban watersheds, on the other hand, were relatively steady throughout the year and nutrients were abundant at optimum times, (Figure 1). A mean of 97% of the nitrogen was discharged in February, March and April from the three agricultural watersheds while about one-half was discharged from urban watersheds in these three months (Figure 2).

Excessive vegetation in streams may exert a secondary and very substantial organic loading during its decomposition. Occurring from time to time, the occasional impairment due to this cause may be of little concern, but I am reminded of the saying that " a fish need be killed only once ".

However, in our work to date in biological surveys, we usually have been more concerned with the standing waters, which, in many cases receive these nutrient-laden streams. The rate of development of multiple-use reservoirs has increased, and, although water of good sanitary quality can be provided, as biologists we are concerned with the possible development of aquatic nuisances and severe limitation of the usefulness of these reservoirs. The Willowdale Reservoir will be supplied by the East Don River. German Mills Creek is a tributary of the East Don and yields about 90,000 lb PO_4 /yr. In addition, a new plant on the East Don near Thornhill will contribute approximately 55,000 lb PO_4 /yr. The implications of adding at least 70 tons of phosphorus in a steady supply each year to a relatively small lake of 65 acres should be apparent. Incidentally, this loading is equivalent to 6,000 bags of superphosphate fertilizer.

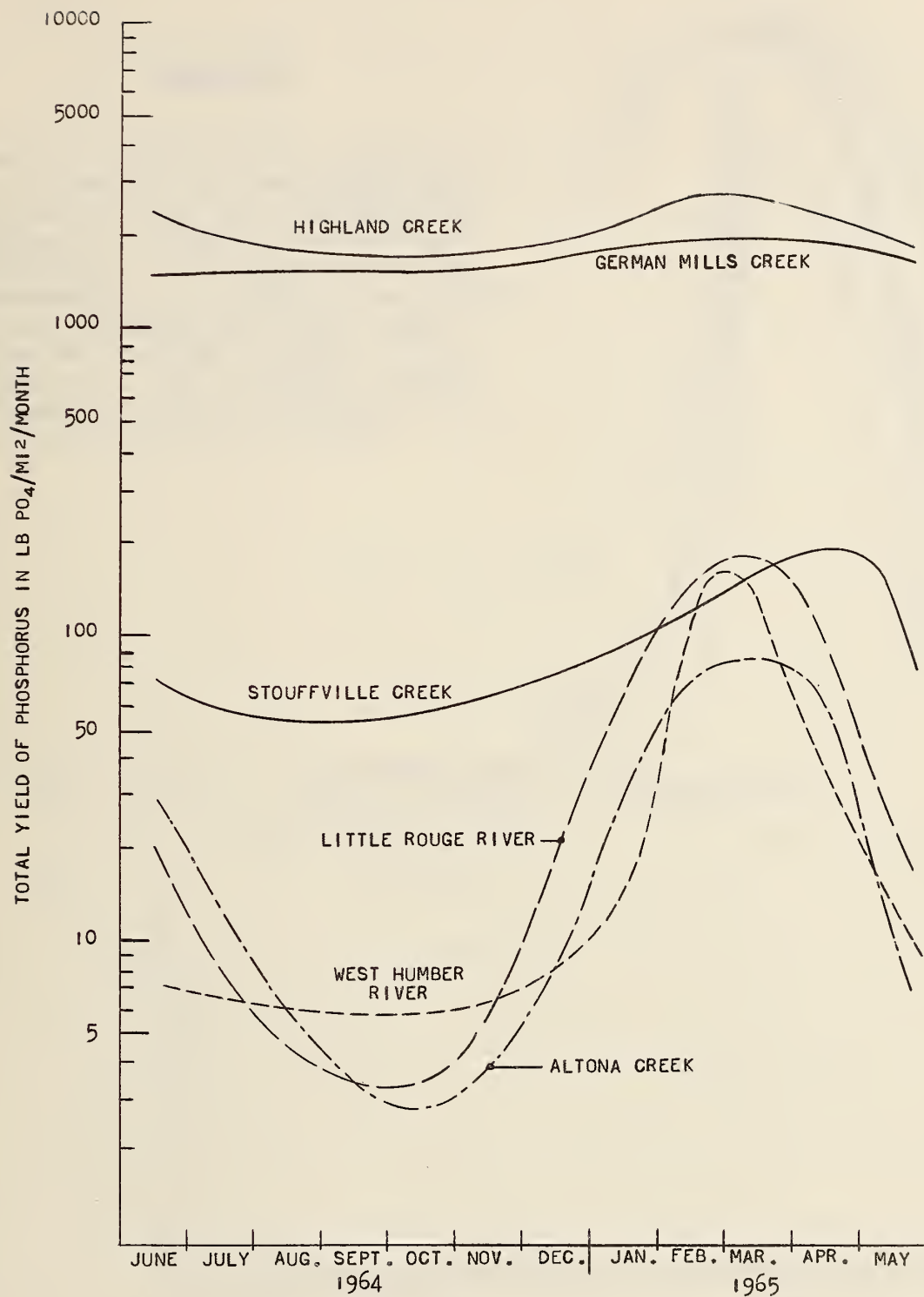


FIG. 1. MONTHLY DISTRIBUTION OF YIELDS OF TOTAL PHOSPHORUS FROM SIX WATERSHEDS IN THE METROPOLITAN TORONTO REGION.

ALTONA	- AGRICULTURAL WATERSHED
WEST HUMBER	- AGRICULTURAL WATERSHED
LITTLE ROUGE	- AGRICULTURAL WATERSHED
HIGHLAND	- URBANIZED
GERMAN MILLS	- URBANIZED
STOUFFVILLE CREEK	- RECEIVES MODERATE AMOUNT OF DOMESTIC WASTES

ADDENDUM

Figure 2 in the paper prepared by M. G. Johnson of the Commission represents only very roughly the yields of nitrogen from several watersheds. The data are to be processed for a paper to be given at the forthcoming Great Lakes Research meeting in April, 1967 in Toronto. An improved presentation of yields of nitrogen will be available at that time.

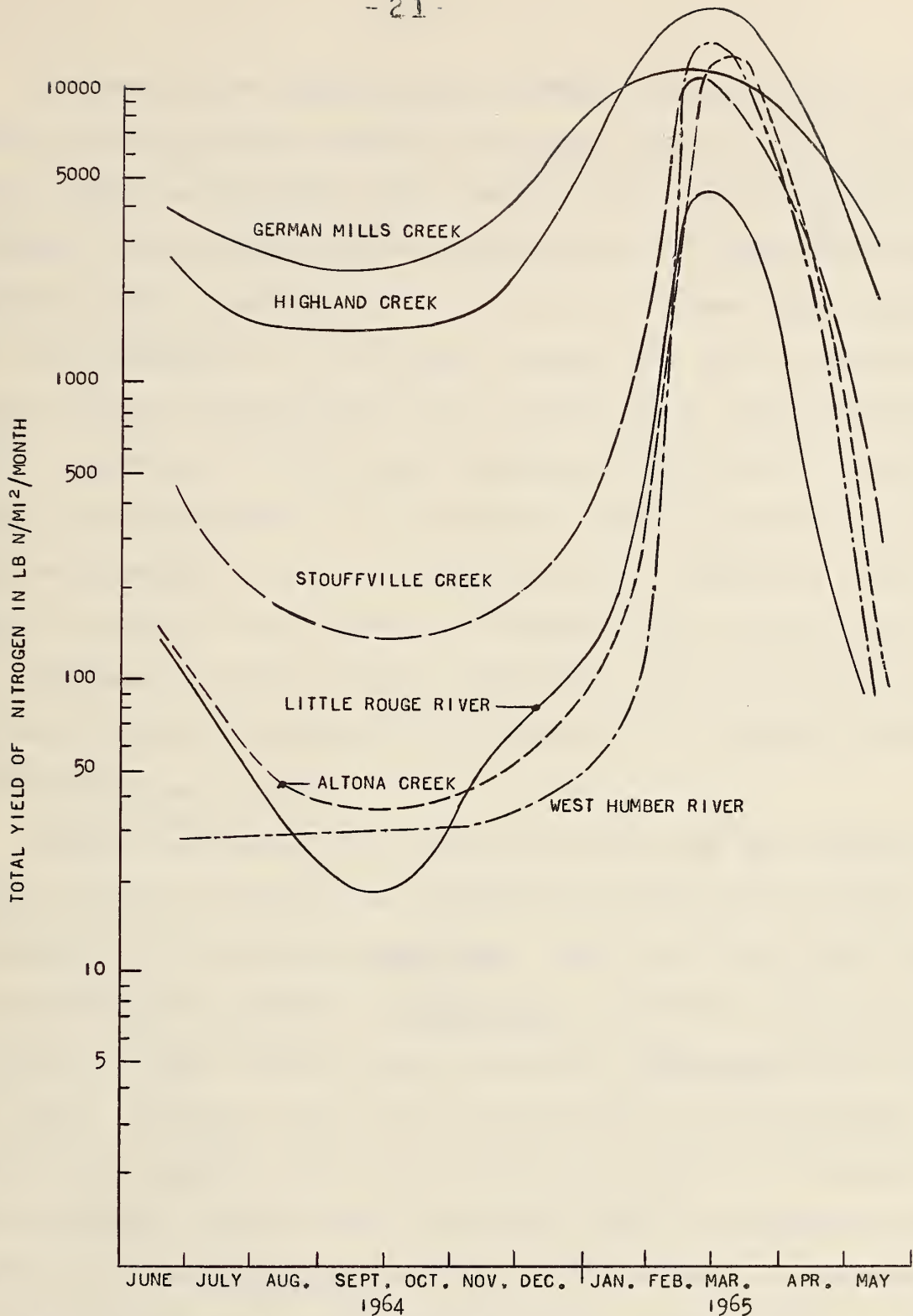


FIG. 2. MONTHLY DISTRIBUTION OF YIELDS OF TOTAL NITROGEN FROM SIX WATERSHEDS IN THE METROPOLITAN TORONTO REGION.

ALTONA	-	AGRICULTURAL WATERSHED
WEST HUMBER	-	AGRICULTURAL WATERSHED
LITTLE ROUGE	-	AGRICULTURAL WATERSHED
HIGHLAND	-	URBANIZED
GERMAN MILLS	-	URBANIZED
STOUFFVILLE CREEK	-	RECEIVES MODERATE AMOUNT OF DOMESTIC WASTES

Obviously the agencies which develop reservoirs will be concerned with this future problem and others like it. But all of us in the pollution abatement field should show equal concern for many reasons, not the least of which is the fear of what effect the discharge of such a reservoir will have on the stream below, particularly if the discharge is a low-level one and the lake is sufficiently deep that thermal stratification has occurred and a septic hypolimnion produced. Actually, the low level discharge can be used to advantage to prevent the development of an extensive septic hypolimnion and probably to decrease the rate of regeneration of nutrients from lake sediments, as shown in our studies on Fanshawe Lake (Johnson and Verst, 1965). Discharge of deeper waters containing higher concentrations of nutrients may be of benefit to the reservoir but possibly detrimental in downstream waters.

Before concluding this brief discussion of the effects of nutrients, I wish to mention the research work which the Biology Branch has carried out on the alga, Cladophora. Neil and Owen (1964) were able to stimulate the growth of Cladophora, by adding phosphorus in the vicinity of "seed rocks" placed along the Cladophora-free shore of Lake Huron. Nitrogen alone did not stimulate its development. This experiment together with the known distribution of problem growths in the Great Lakes suggests that increased levels of phosphorus are responsible for the Cladophora problem. The increase in phytoplankton over the years in Great Lakes waters also has been of interest to the Biology Branch, not only because of the complications which algae may present in water treatment but also with regard to the general study of eutrophication of the lakes (Schenk, 1965).

NUTRIENT REMOVAL

Nutrients in excess amounts will increase as wastewater volumes increase. If anything at all is to be done to control nutrients, it will have to be undertaken at the treatment plant, pond or other facilities.

Approximately 80% removal of phosphorus from sewage was achieved in trials at Lindsay, effecting a decrease from about 20 to 4 ppm using alum and activated silica (Neil 1957). At the present time lab-scale tests are being conducted by the Research Division using lime, alum, iron, caustic soda and activated fly ash. Removal of 85% to 90% of the phosphorus has appeared to be practical. Apparently 96% removal can be achieved in lime treatment with little additional cost for the greater efficiency (Dart, pers. com.).

Phosphorus removal in activated sludge plants may be about 35%. The three plants which we examined, Richmond Hill, Highland Creek and Stouffville, showed reduction of 28%, 40% and 43% respectively. A number of lagoons studied by the Research Division reduced phosphorus by about 60% (Thon, 1964), and nitrogen by approximately 70%. Apparently 80% of the phosphorus was removed in aerated lagoons at Chatham where cannery wastes are treated, but only about 10% was removed in tertiary treatment ponds at Brampton.

Probably many of us believe that lagoons will provide the answer if methods for harvesting and processing algae can be developed. However, my own belief is that phosphorus is present in super abundance. Light is the limiting factor and the algae never synthesize a significant amount of the phosphorus which is supplied to them. The argument probably applies to a lesser degree to nitrogen and to other nutrients as well.

The effluents from operating lagoons contain several times as much phosphorus which passes MPF filtration as that removed, circumstantial evidence that algae (including bacteria as well) do not synthesize a great proportion of the phosphorus delivered to lagoons.

Probably the moderate degree of removal of phosphorus observed in some lagoons is mainly by chemical and physical means, and very likely chemical-physical methods of nutrient removal will be most efficient.

RESEARCH NEEDS

Some of the areas in which biological information is required are:

1. studies on the nutrients and combinations of nutrients which actually limit productivity in various situations, in relation of course, to other chemical and physical factors and biological interactions,
2. the significance of excess concentrations of various nutrients in streams and lakes and what degree of nutrient removal produces desired effects; obviously streams and lakes will show considerable differences,
3. can the yield of nutrients be manipulated with respect to time to advantage?
4. studies on the basic physical-chemical-biological limnology of reservoirs particularly in relation to the development of nuisance growths of aquatic plants and the best use of reservoirs to supply water of desirable quality and quantity downstream.

Obviously there are many other aspects, for example, nutrient cycles, chemical-physical removal of nutrients and other studies of interest to the chemist. However, it should be obvious to all of us, that most studies can best be done by people of varied disciplines working together. We should avoid the single-discipline approach to problems which ramify into many of the sciences. People with the skills and knowledge to cover such wide areas are rare, and, although we should work towards increasing the breadth of knowledge of the individual, the well coordinated multi-discipline approach to many problems will be most rewarding. Each discipline (the chemist, sanitary and industrial engineers, biologist, geologist and others) should take a full and responsible role in the overall work of the Commission. I can think of no task to which this philosophy would apply as well, than the study and control of excess nutrients in the aquatic environment.

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SUMMARY OF DISCUSSION

K. Reichert - Sanitary Engineering Division

Would you comment on the method used to measure phosphorus, and its reliability, in particular when measuring concentrations in the low ranges.

Mr. Johnson

The OWRC method is as in Standard Methods. This measures soluble phosphate or total phosphorus and is accurate to 10-20 ppb. The accuracy may be improved by extraction and concentration of molybdate blue in a suitable solvent or by the use of a longer light path in the colorimeter.

J. Thon - Sanitary Engineering Division

In your talk you made no reference to any limiting value for phosphate. We use the value of 2 ppb. Would you like to comment on this limiting value.

Dr. Hynes

Limiting values for phosphate determination are in the order of 2 ppb. Most references to phosphate determination made in the talk used older methods that were probably not as accurate as those now in use.

Most algae can get by with limiting proportions of phosphate but, if excess phosphate is present they can also store it for future use so it is not very meaningful to talk of limiting amounts in the varied environment of running water.

Kim Shikaze - Industrial Wastes Division

With regard to nitrogen fixation, have any studies been conducted to show whether it is greater in streams than in lakes or vice versa?

Dr. Hynes

No nitrogen fixation studies have been carried out in streams. They have mostly been done in rice fields and in lakes and it is known that nitrogen is not fixed by the organisms unless it is not obtainable from any other source.

J. Theil - Kilborn Engineering

In your book you did not define pollution, especially with respect to Phosphate and Nitrate. Would you like to comment on this.

Dr. Hynes

I never define pollution. This keeps me out of trouble.

Gordon Van Fleet - Sanitary Engineering Division

Might it be possible, under field conditions, to control the growth of algal species in order that we might take advantage of:

- a) increased PO_4^{3-} uptake of a particular species and/or
- b) algal harvesting as a feed by elimination of toxic species?

Dr. Hynes

No information is available, but possibilities do exist in this field.

K. Shikaze

Based on your studies (i.e. Highland Creek) what phosphate removal efficiency would be required by some form of tertiary treatment to reduce phosphate levels in the effluent so that it is below the limiting concentration for algae growth? (If it can be reduced at all to such a level because of other contributing factors).

Mr. Johnson

At present it is not known how much phosphate should be removed. Work is being conducted on nutrient removal in general. As a practical rule the more nutrient removed the better.

It might be possible to allow certain concentrations of phosphate in streams but this quantity might result in excessive concentrations of phosphate in the receiving lake. It should always be kept in mind that phosphates accumulate in lakes.

Dr. Hynes

The growth cycle of algae in streams is similar to the cycle of phosphate concentration but lags behind and is not as pronounced.

There are other factors such as other nutrients, shade and temperature that may also affect the growth of algae in streams.

Also it has been noted that certain species of algae can become acclimatized to changed environments.

F. Guillaume - Research Division

To what extent does natural eutrophication take place?

Dr. Hynes

Eutrophication occurs in the absence of man, but man accelerates the process enormously by his present activities.

Mr. Johnson

Studies at Yale and Indiana on microfossils of the sediments of lakes have indicated that even natural eutrophication proceeds at a significant rate and produces definite changes in the biota.

A. Townshend - Sanitary Engineering Division

What can be the adverse effect of discharging living algae from a waste stabilization pond to the receiving stream?

Dr. Hynes

This occurs in nature when a lake discharges into a stream. It has been found that the lake algae do not survive for a very great distance downstream due to the drastic change in environment. The algae serve as food for higher animals such as insects and also get entangled with vegetation.

You may have noticed that a large number of insects inhabit the area where a stream flows out of a lake. This is because they feed on the rich supply of algae.

Mr. Johnson

In some instances turbulence has been found to inhibit algae growth, for example, at Listowel where the stream is fast and turbulent and altogether unlike the original environment of the algae. Therefore, the nature of the stream will be quite important in this regard.

F. Guillaume

There is disagreement as to whether the unfiltered or filtered BOD should be used in the evaluation of the effluent quality of lagoons and their effects on the stream.

By filtering the sample one also removes other organic material and not just the algae. The most realistic value for BOD should lie somewhere between the filtered and unfiltered values.

K. Symons - Water Resources

The graph for PO_4^{3-} and NO_3^- in lb/sq mile is similar in pattern to the normal hydrograph for a stream. Is the increased flow, flood flow, responsible for the graph or is there also an increase in concentration?

Mr. Johnson

The increase in phosphorus and nitrogen was greater than it would have been with increased flow only.

A. Redekopp - Sanitary Engineering Division

Recently we have had blooms of Synura in so-called virgin lakes up north such as Lake Apsey at Espanola and also at Lake Sasaringa at Cobalt. These blooms have caused severe taste and odour problems. Is there any explanation for this?

Dr. Hynes

Algal blooms are natural phenomena but Synura causes taste and odour problems even when present in small concentrations. Presumably the Synura are not present in heavy concentrations, and one would not expect dense blooms of blue-green algae without pollution.

George Trewin - Sanitary Engineering Division

Can phages be developed to attack undesirable algae, e.g. Synura?

Dr. Hynes

Phages attack only bacteria and some blue-green algae but not the higher more complex algae of which Synura is one.

K. Symons

Microcystis was said to be poisonous, at times. What is the pathogenic component? Is the high nitrogen component related to the poisonous effect?

Dr. Hynes

Microcystis is poisonous at times and not at others. Much work has been done in Ottawa on Microcystis in recent years and many strains are known. The toxin is a cyclic polypeptide, i.e. a ring of amino acids, but it is unknown why it is present in some strains and not in others.

F. Guillaume

Do conditions occur in receiving water, where the nitrate concentration would become limiting? In other words, would nitrate removal be an effective form of tertiary treatment?

Dr. Hynes

I doubt it. Nitrate is always being leached out of the soil and it leaches out far more easily than phosphate.

K. Symons

Is there any evidence of septic conditions in the hypolimnium of conservation reservoirs?

Mr. Johnson

Studies on the Fanshaw Dam showed that with a surface discharge one-quarter of the volume is septic. A thermocline persisted through the downstream one-half of the reservoir.

In 1963 a low level discharge was put into use throughout the summer and the septic hypolimnion was reduced to 10% of its volume in other summers.

Any reservoir of average size and of approximately 25 feet or greater in depth should stratify.

At Bolton a proposed dam 79 feet deep will have four penstocks installed at various levels to allow manipulation of water quality of the effluent.

J. A. Moore - Sanitary Engineering Division

In your book you mentioned toxic pollution of a relatively non-polluted stream where fish were killed. A toxic substance from decaying evergreen needles was suspected. Could this also be from algae? There was a case in Ontario in 1965 where fish were killed in a spring water stream. Could this be caused by either of the above possibilities?

Dr. Hynes

The incident you refer to occurred in Belgium. The fish were not known to have been killed, they simply disappeared. It is possible that algal blooms and Microcystis are toxic to fish, however, this has never been proved. The deoxygenation of water caused by the decay of algal blooms is a more likely cause of fish deaths.

K. Shikaze

It is generally agreed that phosphate is the more limiting nutrient for algal growth. Is the limiting concentration different for a stream than for a lake?

Dr. Hynes

Nobody knows for sure, but on theoretical grounds one would expect the limiting value to be lower in running than in still water. This is because turbulence constantly renews the water at the cell surface, whereas in still water a depleted zone forms round the cell and movement of ions into it is only by diffusion.

Mr. Johnson

Obnoxious conditions due to excessive plant growth may occur in a stream when exposed to phosphorus concentrations in the order of 1 to 5 ppm; however, in a lake concentrations of only a fraction of this amount, say 0.1 to 0.5 ppm, may be associated with problem growths of algae. The level of phosphorus associated with *Cladophora* outbreaks may be even lower.

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